Chapter 1
Introduction: Listening in the Ocean

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Abstract The use of passive acoustic monitoring (PAM) to detect aquatic life continues to increase because PAM devices can be deployed in remote areas and can operate for months or years at a time in a programmed manner to control the recording time, the duration of each recording, and the time to “sleep” to preserve battery power. This introduction will discuss the early history of these tools, their architecture, their uses, and the organization of this book. The architecture of almost all PAM devices is similar in that a microcontroller is used to manage the analog to digital conversion process, the flow of data from either a buffer or directly into storage, and the mode in which the PAM will be used. There are basically two main modes, a continuous mode in which data are collected continuously and a programmed or duty-cycled mode. Some acoustic tags are designed just for short time applications (hours or several days) and are attached by suction cups on swimming animals. This book contains chapters from different researchers discussing some of the interesting and exciting findings they have made by listening in the ocean.

1.1 Introduction

One of the best ways of studying animals living in an inaccessible environment is to use autonomous remote devices that can sense the presence of animals, their movements, activities, and daily patterns. If information is desired on a 24-h basis then the best type of sensor would be an acoustic recorder that can be programmed to turn on at specified intervals for a specified duration and not be on continuously in order to conserve battery power and storage space. The process of turning a device on at a specified interval is commonly referred to as duty cycle. Various types of autonomous passive acoustic recorders (PARs) have been developed to

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study both marine and terrestrial animals. Another more popular terminology for such devices is the acronym PAM (passive acoustic monitor) although in truth these devices are really recorders. These two terminologies will be used interchangeably in this volume.

Starting around 1994, PARs have been used to study marine mammals in the deep ocean and have unveiled a cornucopia of information and understanding of marine life that had not been known or suspected. The purpose of this book is to share some of the amazing and interesting discoveries of life history and life cycles of dolphins, whales, fish, crustaceans, and other organisms that produce detectable sounds in a single volume. We have assembled the leading experts in this field to elucidate their research and finding. Hopefully, as the use of PARs continues and newer types of PARs are developed with increased capability, this volume will be but the first of future volumes on not only the use of PARs to study marine life but also terrestrial life on our planet.

1.2 Early History

There has been a continual evolution in the development of PARs over the years, but many do not realize that we have our geophysicist colleagues to be thankful in developing the precursor to the modern PAR and pushing the remote recording technology further. Among the various interests of geophysicists is the detection and localization of low-frequency seismic signals that propagate on the ocean floor. In any long-term study, researchers would just as soon deposit a package that can collect data over as long a time period as possible and retrieve the package at a later date to access the data. Byrne et al. (1987) at the Hawaii Institute of Geophysics developed a recording package that would eventually detect the signals of some baleen whales. They developed a special automatic gain control circuitry that provided 132 dB of dynamic range to extend the 40 dB dynamic range of an analog magnetic tape cassette tape recorder (a standard procedure in the HIG Ocean-Bottom Seismometers). The tape recorder motor was slowed down so that 14 days of operation could be achieved with a single C-90 cassette tape. Then a time-delayed circuit was used to sequentially turn on a series of five cassette recorders after a 13-day delay between the turn on of the previous recorder to the next recorder, thus providing 1 day of overlapping data from the previous recorder. The recording system provided 66 days of continuous recordings with an analog bandwidth of approximately 44 Hz.

Duennebier et al. (1987) reported on the low-frequency noise levels, signal-to-noise ratios, and noise sources detected by the geophone system discussed by Byrne et al. (1987). They reported the detection of a “large biological source.” At the time, they were not aware of the characteristics of different baleen whale calls but later Duennebier described the sounds as coming from fin whales (personal communications). Other geophysicists began to report on the presence of baleen whales on various types of bottom-mounted Seismometers between 1994 and

1995 (McDonald et al. 1995; Matsumoto and Fox 1996). The geophysicists' community also continued to devise different methods to gather their data which eventually paved the way to the first generation of modern autonomous remote passive acoustic recorders developed mainly to record the sounds of whales and dolphins.

1.3 The Anatomy of Modern Autonomous Remote Underwater Acoustic Recorders

There are a host of different models and type of autonomous remote underwater acoustic recorders developed by research institutes, universities, and commercial endeavors. Some of the vintage models that arrived on the scene during the 1994–1997 period include the Haruphone (designed by Haruyoshi Matsumoto at the Hatfield Marine Science Center in Oregon), the Lcheapo (developed at Scripps Institute of Oceanography), the Cornell University Pop-up, and the Greenridge bowhead whale recorder (Greene 1997). These were some of the first PARs that moved from a tape technology to microcontroller technology. The anatomy of a typical PAR is shown in Fig. 1.1. Some of the first microcontrollers used were the Tattletale 7 and 8 manufactured by Onset Computers and the CF1 and CF2 from Persistors Instruments, Inc. The hard drive consumes the most power. In some models, the compact flash serves as an intermediate low-power storage device and data are transferred to the hard drive only when the compact flash reaches a

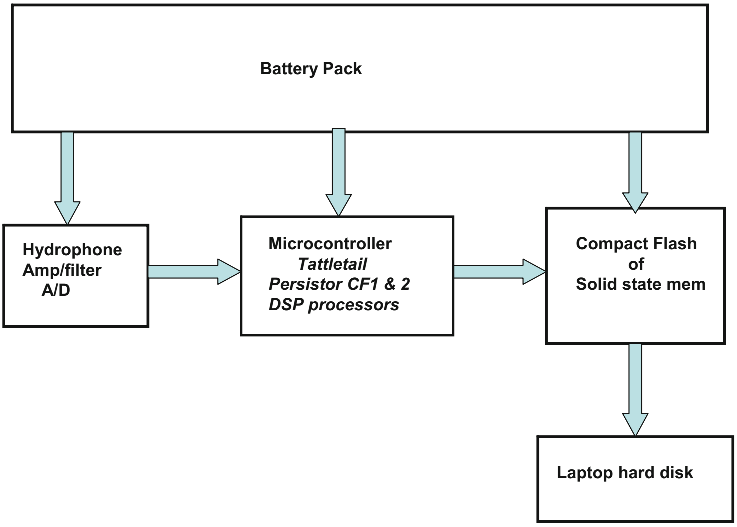

Fig. 1.1 Anatomy of an autonomous remote acoustic recorder

predesigned storage level. This process is important in minimizing the use of the hard drive and conserving power while not losing any data. The Cornell University Pop-up, using a Tattletale 8, was the probably the first system designed specially to capture whale sounds. Today there are a number of different types of PAR that are commercial available or available through different types of agreements between research institutes and university laboratories.

The major differences in the capabilities of the various types of PARs include differences in the sampling rate of the analog-to-digital (A/D) converters, the frequency range of the hydrophones, the amount and type of data storage, power requirements, and size. Some are specialized mainly for certain types of animals while others are more general in scope. Some are packaged in ways that have certain depth limitations; however, the internal electronics can be repackage in more robust housings for deeper depth with hydrophones suited for the desired depth. There is one PAR, the C-POD that does marine mammal monitoring in a totally different manner. The C-POD is designed to detect cetacean click signals and logs the time, center frequency, sound pressure level, duration, and bandwidth of each click and stores the results instead of the acoustic signal. This technique minimizes the amount of storage space needed and can monitor the environment continuously. A small memory size of 4 GB will last for approximately 4 months.

1.4 Examples of Three Early PARs

1.4.1 Cornel Pop-Ups

The Cornell Bioacoustics Laboratory developed an autonomous remote acoustic recorder that can be deployed to a depth of 6000 m and later retrieved by sending a special acoustic signal from the surface to detach it from its mooring, allowing it to pop up to the surface, and hence was given the name “pop-up”. The electronics consist of a Tattletale 8 microcontroller from Onset Computer Corp. that has an onboard 8-channel analog-to-digital converter with a throughput of 100 kHz to acquire acoustic data from the hydrophone that is connected to it, with the data being stored on 128 GB of compact flash memory and eventually to hard disks. A schematic of the pop-up subsystems is shown in Fig. 1.2 with the electronics housed in a 17-in diameter glass sphere. The microcontroller can control the turn-on and record phase and the turn-off and sleep phase under software control. Therefore, the battery power can be minimized and the unit deployed for an extended period until either the capacity of the hard drive is reached or the batteries are drained.

A deployed pop-up is connected to an anchor with a stainless steel wire which can be “burned” to release the pop-up form the anchor. Acoustic communications from the surface to the pop-up occur with the use of a surface controller unit and a hydrophone. When the pop-up receives the appropriate signal from the surface, it

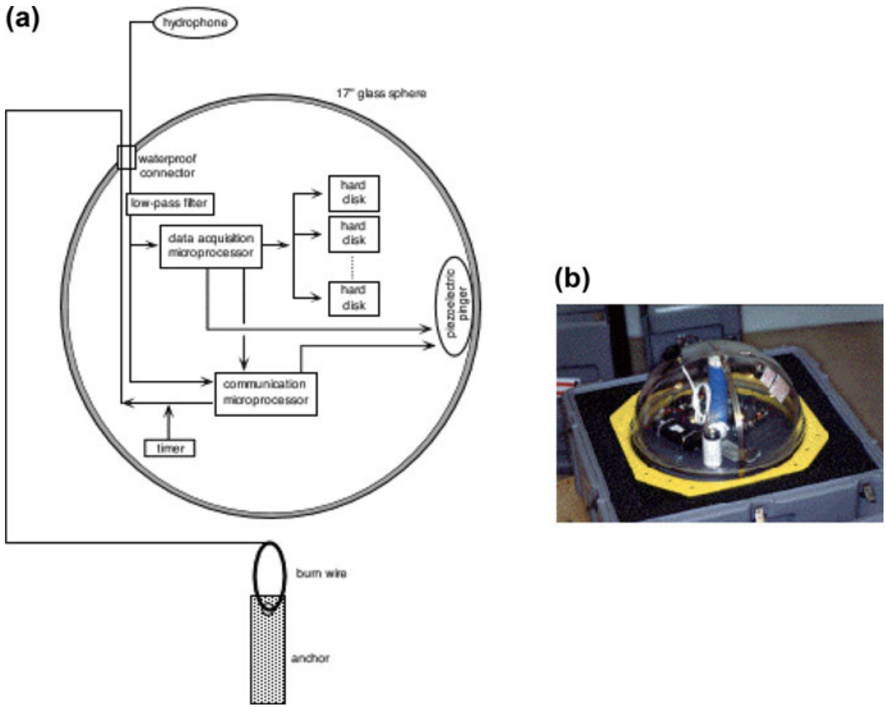

Fig. 1.2 (**a**) Schematic of the "pop-up" and (**b**) a pop-up in a shipping container

acknowledges by emitting its own acoustic response signal. Depending on what signal is sent from the surface vessel, the pop-up responds either with its acoustic response alone, or by triggering the burn wire to release the anchor. A VHF radio beacon is housed with the pop-up unit which will begin transmitting as soon as the unit reaches the surface and the antenna is out of the water. A high-intensity strobe light is also automatically turned on when the device reaches the surface so that the unit can be easily spotted and retrieved. Once the pop-up is retrieved, the unit can be refurbished by removing the hard disk, and downloading the acoustic data to a computer. The information on the disk reformatted or is then erased, the disk reformatted or replaced, new batteries are installed, and the unit is ready for redeployment.

1.4.2 Scripps HARP

Scripps Oceanographic Institute has long been involved with developing remote autonomous seafloor data loggers, mainly for geophysical research, and eventually developed the LCheapo (Tattletale-8 system) around 1998. This trend eventually led

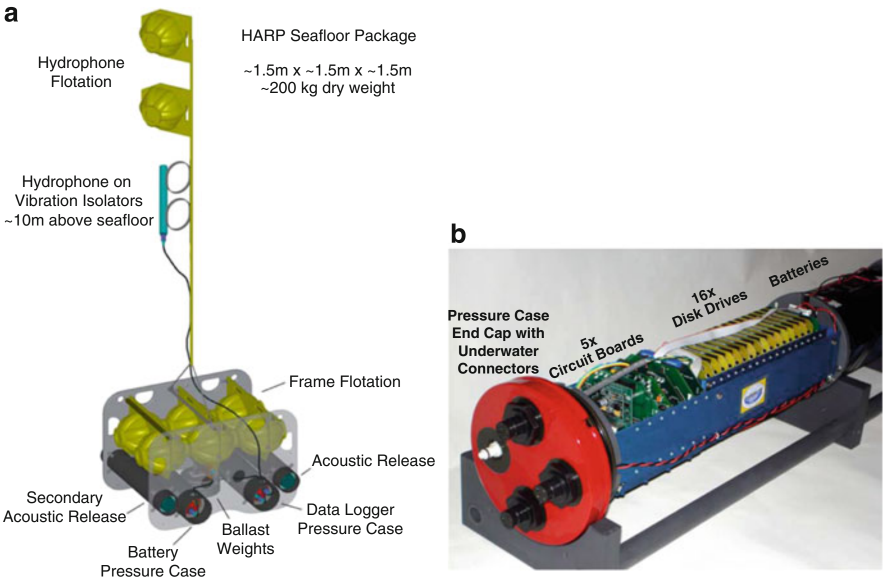

Fig. 1.3 (**a**) A schematic of the HARP system deployed on the ocean bottom, (**b**) the internal configuration of the HARP recording package

to the development of a seafloor data logger for recording baleen whale calls and songs, the ARP (Acoustic Recording Package) in 2003. The ARP sampled at a low frequency of 500 Hz. However, it served as the precursor for the highest sampling rate seafloor acoustic recording system today, the HARP (high-frequency acoustic recording package), to perform continuous long-term monitoring in remote locations under various weather conditions and independent of daylight (Wiggins and Hildebrand 2007). Development of the HARP was motivated by the need for a broader-band, higher-data capacity system capable of autonomously recording toothed whales and other marine mammals for long periods. A picture of the HARP system deployed on the bottom is shown in the left panel of Fig. 1.3 and the HARP module acoustic package is shown in the right panel of Fig. 1.3. The acoustic recorder is controlled by a 32-bit 20 MHz Motorola microcontroller with an Analog Devices 16-bit A/D converter used to digitize acoustic signals detected by the hydrophones. The sampled data are stored temporarily into a data buffer consisting of 16 2 MB SRAM chips until about 30 MB of data are collected and then the data are sent to one of 16 laptop type hard drives for permanent storage via an Ethernet 10BaseT link. A total of 1.92 TB of data storage capacity is available so that 55 days of continuous sampling at a sample rate of 200 kHz can be achieved. Lower sampling rates will allow for longer total recording time and so would scheduled sampling where the recorder is turned on for a period of time between off or sleep periods.

The HARP comes with two hydrophones, one for low frequencies from 10 Hz to 2 kHz and a high-frequency one from 1 to 100 kHz. An International Transducer ITC-1042, spherical omni-directional transducer is used for the high-frequency hydrophone. The low-frequency hydrophone consists of six cylindrical Benthos AQ-1 transducers connected in series for increased sensitivity. A 40-dB gain preamp is used for the low-frequency recordings and an 80-dB gain preamp is used for the high-frequency recordings. Both signals are prewhitened for the frequency variation of typical ocean ambient noise.

1.4.3 HIMB/PIFSC Ecological Acoustic Recorder (EAR)

The ecological acoustic recorder (EAR) was developed jointly between the Hawaii Institute of Marine Biology (HIMB) and the Pacific Islands Fisheries Science Center (PIFSC) and has been used in the field since 2006. It was designed to be a bottom-moored passive acoustic logger with a capability for long-term monitoring of the underwater ambient sound field (Fig. 1.4). The EAR is a digital recorder based on a Persistor™ CF2 microprocessor. It is a low-power system that records continuously or on a programmable duty cycle and is also capable of responding to sounds detected within a pre-adjustable bandpass filter. It offers a maximum sampling rate of 125 kHz.

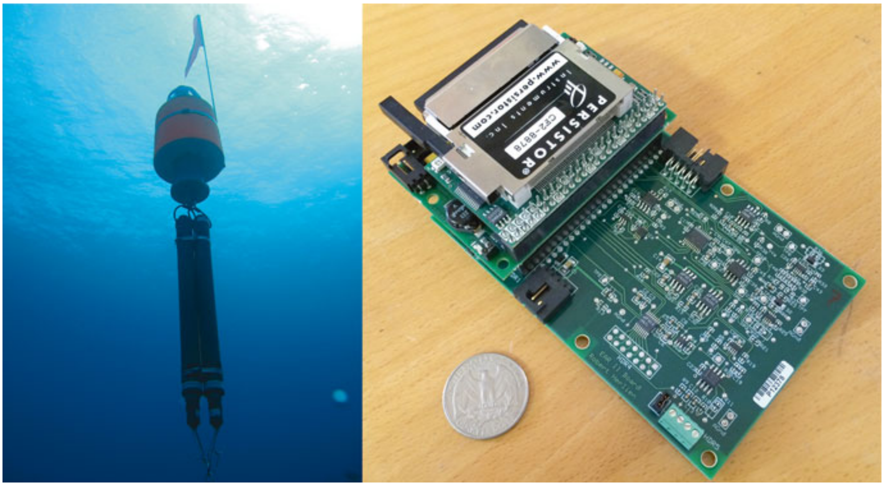

Fig. 1.4 *Left*—EAR packaged for mounting on the bottom of the ocean, *right*—Internal electronics showing a mixed signal preprocessing board with analog amplification-filtering and analog-to-digital conversion controlled by a Persistor CF2 microcontroller

1.5 Acoustic Recording Tags

There is another class of autonomous acoustic recording devices that are small and light enough to attach to animals in the field using support structures that are connected to suction cups. The architecture of such tags is essentially the same as shown in Fig. 1.1 with different microcontrollers and solid state memory.

1.5.1 The Bioacoustic Probe/Accusonde

Many marine animals rely on acoustics to capture prey, avoid predators, reproduce, and navigate, yet we know very little of the type of acoustic signals marine mammals encounter in the open ocean. The ocean is a very noisy environment, especially at low frequencies. In order to measure and record the noise field that marine mammal swims in, Burgess et al. (1998) developed the compact acoustic probe (CAP) which was a data logger controlled by a TattleTale 7 with a 340 Mb hard disk enclosed in a 36 cm long, 10 cm diameter cylindrical hydrodynamic housing capable of withstanding 2000 m depth. It was first used with northern elephant seals to monitor the low-frequency sounds from the ATOC (acoustic thermography of ocean climate) source as tagged elephant seals would swim in the vicinity of the source (Fletcher et al. 1996). These seals regularly haul out on land, allowing easy access for attachment and recovery of instrumentation packages. These animals migrate annually, swimming thousands of kilometers north and west from California and during this migration they experience a wide variety of acoustic environments (Le Boeuf et al. 1993).

Eventually, the CAP gave way to the biological acoustic probe (Bprobe) shown in Fig. 1.5. It combines a hydrophone, pressure (depth), temperature, and acceleration sensors, a data acquisition unit, data storage, and a field replaceable battery in a single, self-contained package. The heart of the Bprobe is a programmable microcontroller chip. A 16-bit A/D converter that can sample the hydrophone output at rates up to 20 kHz and stores the results in a 1 GB flash memory is used. The user can select a hydrophone amplifier gain of 0, 10, and 20 dB. The Bprobe can be programmed to

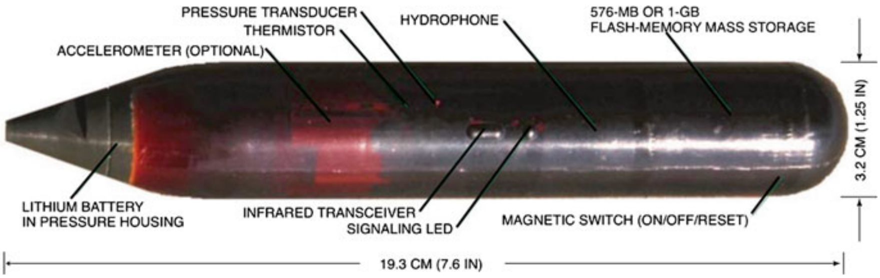

Fig. 1.5 Picture of the Bprobe (courtesy of W. Burgess)

Fig. 1.6 An elephant seal carrying an instrumentation package preparing for its winter migration (courtesy Burney LeBeouf)

sample at specified intervals for a specified duration and between sampling intervals the probe can be put to sleep to conserve battery power. A total of approximately 41 h of operation time can be achieved. The probe is small, light weight, and is encapsulated in polyurethane epoxy. Communication with the probe for setting of the A/D sampling rate and the hydrophone gain are done via an infrared serial link that operates at a speed of 5.3 kB/s.

With this instrumentation package, researchers can determine if diving marine mammals make active sounds, measure the frequencies and levels of sounds diving seals encounter in their environment, and have the acoustic data related to diving behavior of elephant seals (Burgess et al. 1998). A picture of an elephant seal carrying a Bprobe on its back is shown in Fig. 1.6. An example of the acoustic signal received by a seal is shown in Fig. 1.6, with the depth of dive shown above the color sonogram. Most of the received signals had frequencies in the range of 20–200 Hz. Snapping shrimp, cetacean sounds, boat noise, seal swim strokes, and heart beats are clearly audible in some of the data. Flow noise, correlated with swim speed, suggests that optimal time for acoustic sampling would be when the seals are swimming slowly. Results of several deployments have indicated that it is also feasible to obtain long-term, reliable, quantitative, and noninvasive cardiac monitoring of elephant seals and other marine mammals. This capability has been an important bonus to the project.

In 1997, three early versions of the Bprobe were mounted on northern elephant seals just prior to their annual migration from California to Alaska. Two of the packages were recovered after over 4 months at sea (Burgess et al. 1997). The hard disks contained measurement of pressure, temperature, ambient noise as well as acoustic signatures of swim speed, swim stroke rate, respiration, and cardiac function. One subject swam across the northeastern Pacific averaging 58 dives per day with a maximum dive depth of 780 m during the 26 days that the logger batteries supported data acquisition. The other subject swam along the West Coast, diving 81 times per day with a maximum dive depth of 770 m. The results suggest that electroacoustic packages

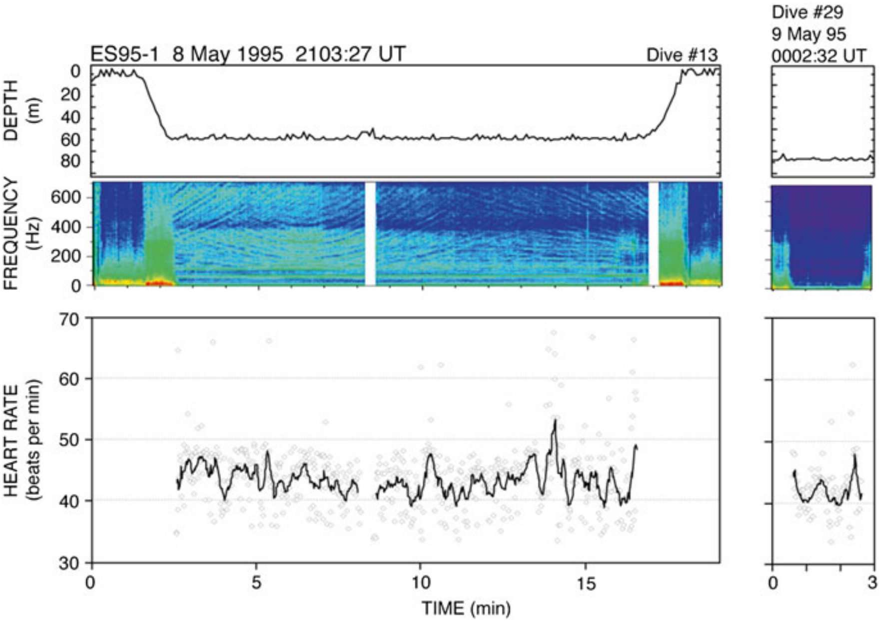

Fig. 1.7 Example of the acoustic signal received by the instrumentation package on a diving elephant seal (courtesy of W. Burgess)

offer a comprehensive and reliable means of sampling acoustic stimuli and associated behavior for free-ranging marine animals over long periods at sea (Fig. 1.7).

A unique application of the Bprobe was devised by Thode et al. (2004) in which a number of them were used as the element of a vertical line array to measure the songs emitted by humpback whales in Australian waters. The use of Bprobes in an array configuration allows for a tremendous amount of flexibility since the sensor spacing can be readily changed and the requirement of a multiconductor power and signal carrying cable is eliminated. In order to utilize this "insta-array," Thode et al. (2004) had to develop a procedure to time-synchronize the recorded data to within a ms or less. The raw acoustic data may be offset in time by several seconds because they cannot be precisely activated at the same time. Thode et al. (2004) first made use of an external broadband signal that would allow synchronization of the probes spaced 3 m apart to with 10 ms, by calculating the cross-correlation function of the signals measured by a pair of probes. They next utilized a global inversion algorithm to maximize the fit between measured acoustic data and the output of a propagation model, a process referred to as "geoacoustic inversion" or "focalization" (Collins et al. 1992). Finally, they were able to exploit the spatial coherence of ocean ambient noise. Providing that the Bprobes are not spaced too far apart, there should be a high correlation of the ambient noise recorded by each probe. The relative difference in timing of each probe can be determined by cross-correlating the signals from each probe with the other probes in the array. The tilt in the line array caused by current was also monitored so that correction for tilt could be made.

1.5.2 Digital Acoustic Recording Tag: D-tag

Another successful acoustic tag or probe that was developed by Mark Johnson at Woods Hole Oceanographic Institute (Johnson and Tyack 2003) is called the D-tag. It has a complementary function to the tag developed by Burgess. It too uses a DSP module to control acoustic data acquisition and storage as well as the measurement of various parameters such as acceleration, depth, temperature, orientation, and magnetic field strength. The principle differences between the Bprobe and the D-tag are imbedded in the design objectives of both tags. The Bprobe was designed to be deployed over a long period of time in the order of months and be used with animals that emit low-frequency sounds and encounter low-frequency noise. The D-tag was designed to measure high-frequency sound emissions on a continuous basis for a short period of time in the order of several hours. Sampling rates as high as 196 kHz for a 12-bit A/D have been achieved with the D-tag and still higher sampling rates are being considered (Tyack, personal communications). The D-tag was designed to be flexible in terms of modifications and therefore not necessarily "user" friendly except to a small cadre of well trained users. The Bprobe sacrificed flexibility for user friendliness and simplicity in operation. The D-tag is packaged in a bag of oil so that modifications can be done as needed. A picture of the D-tag electronics is shown in Fig. 1.8. A complete tag with suction cup mounts is shown in Fig. 1.9. A burn-wire attachment between the housing and the suction cup is used to release the vacuum seal so that the tag can be released off the animal.

The Dtag has been used with northern right whales, sperm whales (Johnson and Tyack 2003), Blainville's beaked whales, *Mesoplodon densirostris*, and Culvier beaked whales, *Ziphius cavirostris* (Johnson et al. 2004; Madsen et al. 2005). The deployment of the Dtags on the beaked whale resulted in some very interesting data, providing extremely important insights into the echolocation process of beaked whale. One Culvier beaked whale performed one foraging dive of 50 min to 824 m. One of the Blainville's peaked whale made six foraging dives to between

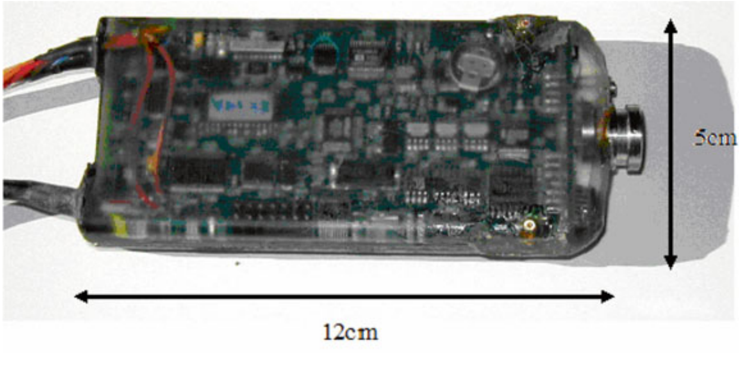

Fig. 1.8 An encapsulated electronic package of the D-tag (from Johnson and Tyack 2003)

Fig. 1.9 Complete tag including plastic fairing floatation and two suction cups (from Johnson and Tyack 2003)

655 and 975 m in 15.4 h while the tag was on the animal. The second Blainville's beaked whale made two deep dives to 730 and 815 m in the 3 h that the tag was attached to the animal. Echolocation signals were not detected until the whales were at least 200 m deep after which they clicked continuously. The *Ziphius* started clicking at an average depth of 475 and stopped clicking when they started their ascent at an average depth of 400 m. The *Mesoplodon* began clicking at an average depth of 400 m and stopped clicking when they started their ascent at an average depth of 720 m. Click intervals during much of a dive varied between 0.2 and 0.4 s. As the whales apparently closed in on their prey, the click rate increased to about 250 clicks/s.

Johnson et al. were also able to record signals that may have been emitted by conspecifics. Two of these signals are shown in Fig. 1.10. The spectra of the two clicks shown in Fig. 1.10 suggest that these beaked whales emit echolocation clicks with peak frequencies between 30 and 40 kHz, and that the spectra of the clicks can extend beyond 45 kHz (the Nyquist frequency of the data acquisition system). These two clicks are the widest band clicks recorded for beaked whales. Besides measuring click from conspecifics, the D-tag has also been able to detect the echoes from prey and other organisms (Madsen et al. 2005). The outgoing signal (measured in the back of the sound source) and the echo from a prey are shown in Fig. 1.11.

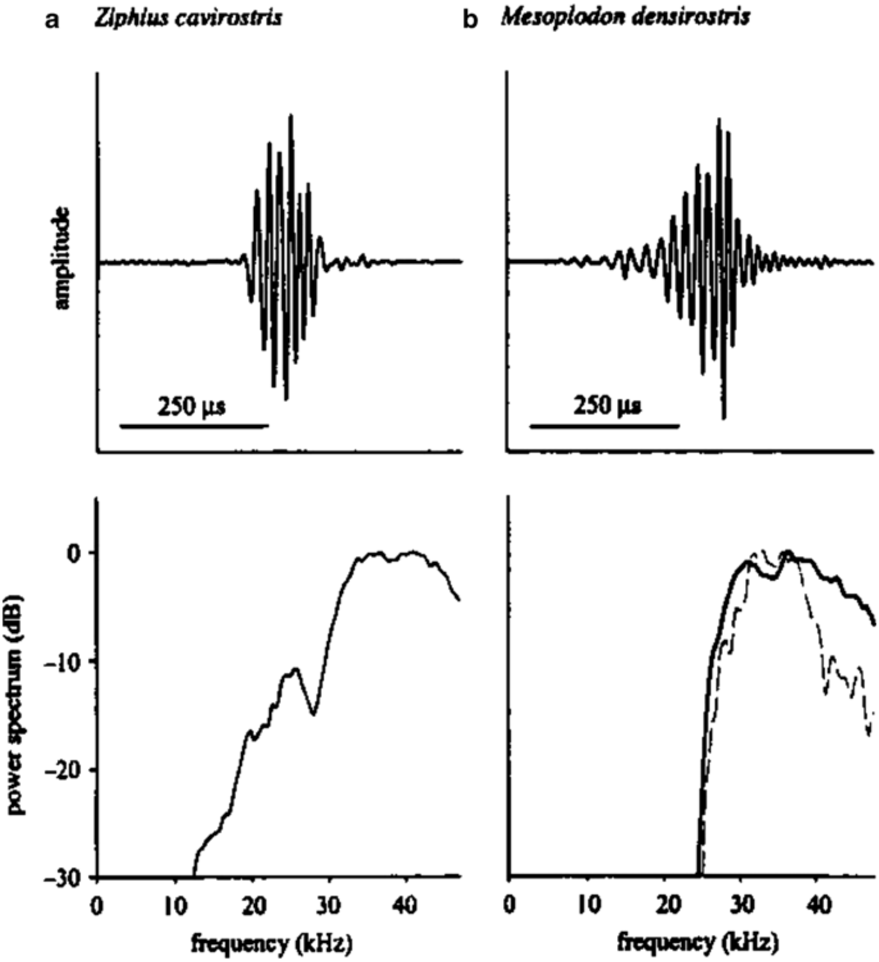

Fig. 1.10 Waveforms and spectra of echolocation clicks seemingly emitted by conspecifics (**a**) *Ziphius cavirostris* and (**b**) *Mesoplodon densirostris* (from Johnson and Tyack 2004)

1.5.3 A-Tag

Akamatsu et al. (2000) used a simple tag to study the echolocation behavior of the finless porpoise (*Neophocaena phocaenoides*) and the Chinese river dolphin, baiji (*Lipotes vexilolifer*). A peak-hold circuit is used to capture the peak output of the echolocation signal and the peak is recorded by a Sony ICD-80 integrated circuit recorder. With this simple device, the time of occurrence and peak amplitude of echolocation signals could be recorded. During nonecholocation periods greater than 1 s, the recorder was turned off to conserve battery power. The data logger was

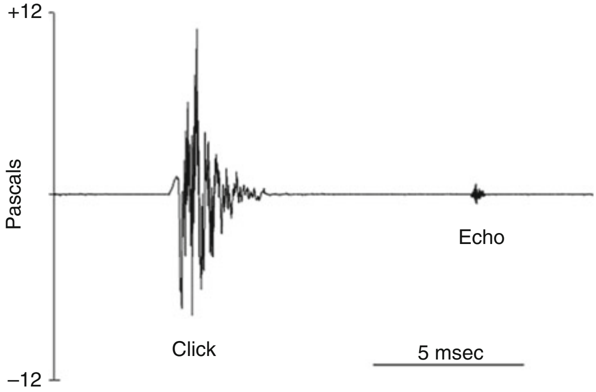

Fig. 1.11 An echolocation signal measured by the D-tag located behind the blow hole of a Blainville's beaked whales (*Mesoplodon densirostris*) and the corresponding echo from a prey (from Madsen et al. 2005)

used by capturing the subject, attaching the tag with a suction cup, and then releasing the animal. A second tag or data logger that measured behavioral information such as depth, swim speed, and the tilt angle of the subjects was also attached to subjects (Akamatsu et al. 2000).

The *A-tag* was originally developed to observe biosonar behavior by tagging on dolphins and porpoises in the wild. In recent years, the *A-tag* has been applied for acoustic transects to count the number of dolphins and porpoises, and for long-term stationed observations. The *A-tag* can be attached on a rope towed from a boat, on a pipe fixed beside a water break, or on an animal using a suction cup. The *A-tag* is enable to record sound pressure at each hydrophone as well as the sound source direction calculated by the sound arrival time difference between two hydrophones (Akamatsu et al., 2005). Identification of each sound source can be used to discriminate each phonating animal individually. The *A-tag* is a small and stand-alone system. The water resistant body of the *A-tag* sizes 21 mm in diameter and 108 mm in length + external stereo hydrophones (see Fig. 1.11). All of the data are stored in the flash memory of the *A-tag* and are downloaded after retrieval. The *A-tag* works up to 40 h by CR2 lithium battery (standard type) and 1 month by two D cells for long-life stationed deployments (optional).The *A-tag* does *not* record the sound waveform. It is an event recorder of each pulse having a sound pressure level over the preset detection threshold level, although the 70 kHz high-pass filter on the *A-tag* rejects undesired low-frequency noise. Chapter 10 by Dr. Tomonari Akamatsu, the driving force in the development of the *A-tag*, will discuss the design and application of the tag with considerably more details (Fig. 1.12).

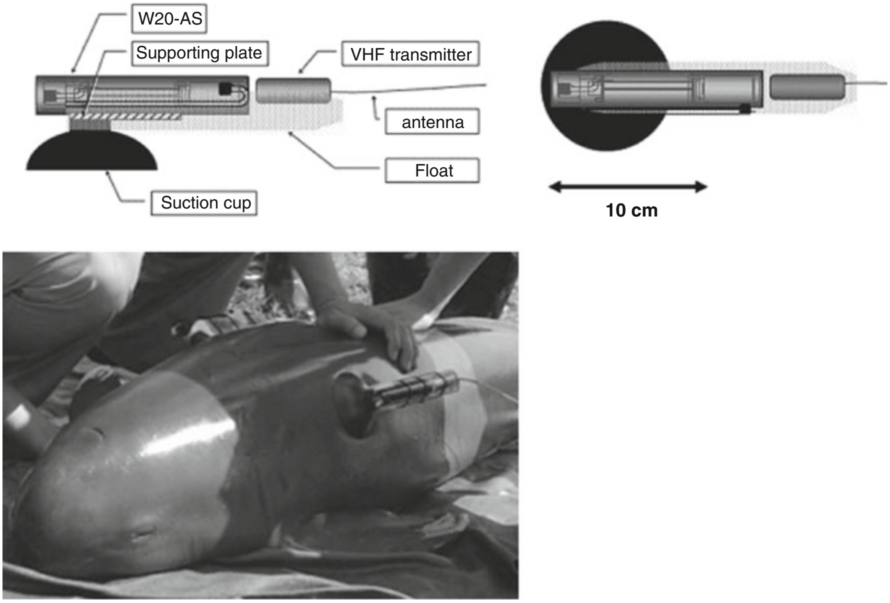

Fig. 1.12 Drawing of one version of the A-tag and its placement on a finless porpoise

1.6 Discussion

1.6.1 Current State of Development

The field of electronics and computer technology continues to expand rapidly, especially in the area of cell phones and mobile devices, and PAM developers have taken good advantage of the new microcontrollers with higher speed, lower power requirements, and more versatility. Coupling this growth with the growth in electronic memory and the development of loss-less data compression algorithms has fueled the development of second and third generation PAM devices. The first generation of PAM devices used laptop hard drives which require almost all the battery power in a PAM device. Today, these laptop drives have been replaced by electronic memory which require considerably less battery power. New microcontrollers have more programmable capabilities so that the microcontroller can perform more functions, including supervision of multichannel data acquisition and data management and data flow. Since about 2010, a host of new PAM devices, too many to list without the danger of excluding some, have become commercially available. These all use more advanced and powerful microcontrollers than the first generation of devices. They all use solid state memory such as SD memory cards which can be stacked to increase storage space. Solid state memories not only use considerably lower power than laptop hard drive but are much faster so that faster data acquisition can be achieved with less of a need for large buffer memory.

The use of single-channel PAM has provided much important data and information and has allowed researchers to gain a comprehensive understanding of how marine mammals utilize their environment. The next step in the development is to have multiple PAM devices that are synchronized so that whales and dolphins can be localized and tracked in three-dimensional space. Drift in the crystals that control the clocks within individual PAM is the major culprit in this area so that multiple PAM devices who's clocks have been synchronized before deployment will no longer be synchronized as the time of deployment increases. One way to handle the synchronization problem is to have a surface buoy extending from PAM devices deployed on the bottom that will receive GPS timing information. However, in many if not most application, having a surface buoy is not desirable because of the danger of damage or theft. Having a cable extending from the ocean bottom to the surface will also present a potential hazard to the marine mammals that are being studied. If a surface buoy is integrated with a PAM device, there is the possibility of near real-time data acquisition using a satellite link or radio transmission back to a land base. In order to utilize radio links, it would be best if the microcontroller could process received data in real time and develop a summary report, such as the number of detections of particular species over a specific time interval while the preprocessed data are stored on-board in electronic memory. In such a system, the amount of data that will be sent via a radio link would be minimized. Such an approach has been taken by use of the Sea-Glider (Klinck et al. 2012). An Iridium satellite transmission was made every time the glider surfaced and directed its tail containing the antenna toward the sky.

1.6.2 Organization of This Book

This book will focus mainly on results of observations of different species of marine animals, with a heavy emphasis on cetaceans recorded in different areas of the world by different devices as in Chaps. 2–14. The second chapter discusses the use of the HARUphone in research on blue whales. The HARUphone was probably the first autonomous portable passive recording buoy used to study animal sounds in the ocean. It was developed for seismic research by scientists at the Pacific Marine Environmental Laboratory of the US National Oceanic and Atmospheric Administration at the Oregon State University Hatfield Marine Science Center. They were first deployed in the Gulf of Alaska as early as spring of 1996 (Matsumoto and Fox 1996; Fox et al. 2001) and it soon became apparent that baleen whale signals, especially blue whales signals, were being recorded.

Another early PAM device developed and deployed in 2000 was the Acoustic Recording Package (ARP) (Wiggins 2003) which was used mainly to study baleen. Like the HARUphone, the development of the ARP had a seismic research origin as seismologists from Scripps Institute of Oceanography realized that baleen whales calls were being recorded on their seafloor array of seismometers (McDonald et al. 1995). The development of the ARP was soon followed by the most sophisticated autonomous recorder, the HARP (high-frequency acoustic recording package) by the Scripps group (Wiggins and Hildebrand 2007). Two noteworthy features of the HARP are its high sampling rate of 200 kHz and its high data storage capacity of 2 TB which included data compression. Some of the results from research using the ARP and HARP are discussed in Chap. 3.

Chapters 4–7 will discuss results obtained with the three different types of PAM devices. Chapters 4 and 5 will discuss signals from marine animals in different ecosystem in the western Pacific. Sounds from snapping shrimp, fish, and odontocetes in a coral reef environment recorded using an EAR will be the subject of Chap. 4, while Chap. 5 will focus on echolocation or biosonar signals used by deep diving odontocetes while foraging. Results from recordings with the Environmental Acoustic Recording System (EARS) buoy mainly used in the Gulf of Mexico will be the subject of Chap. 6. The CPOD and TPOD are PAM devices that operate on a different principle than the devices discussed in Chaps. 2–6. They are designed to detect echolocation clicks within an adjustable band-passed frequency range and the results of their use will be discussed in Chap. 7.

Cabled acoustic observatories have been in existence since the early 1960s for military applications in the form of the SOund SUrveillance System (SOSUS). However, the data collected by SOSUS arrays have not been available except under exceptional circumstances to a civilian scientist. In recent years there have been a number of beaked whale strandings that have been linked to Navy mid-frequency sonar activities (D'Amico et al. 2009) and so the Navy has installed a hydrophone array system entitled Marine Mammal Monitoring on Navy Ranges (M3R) in several Navy underwater ranges in U.S. waters. Chapter 8 discusses some results of detecting and tracking beaked whales with the M3R system.

A unique observatory in Antarctica titled “The Perennial Acoustic Observatory in the Antarctic Ocean” with an emphasis of on pinniped sounds that is a cabled system with a radio link to a base station at which batches of data are transmitted to a home station in Germany via a satellite link will be covered in Chap. 9. This will be followed by a chapter on the seasonal presence of five species of baleen whales in Hawai’ian waters obtained by the Station Aloha Cabled Acoustic Observatory that is moored close to the bottom at 4700 m depth at a distance of about 100 km north of the island of Oahu, Hawaii.

Pinniped sounds recorded in the polar ocean in the artic is the topic of Chap. 11. A Passive Aquatic Recorder (PAL) was used to collect some of the pinniped sounds. The PAL is a unique PAM in that it collected four series of sounds of 1024 points at a sampling rate of 100 kHz (Nystuen et al. 2010). Each sample is separated by 5 s, and the FFT of each series is calculated and compressed to 64 frequency bins and stored on disk. The whole sequence of event required 15 s. The PAL was originally developed to collected ocean environmental acoustic signals.

The sounds produced by deep dwelling fishes are covered in Chap. 12 followed by sounds recorded from benthic shrimp in Chap. 13. Chapter 14 will be devoted to the information obtained with an acoustic tag on different species of dolphins.

The last chapter on signal processing will wrap up this book. The last chapter is especially important since the recorded sounds are only valuable if scientific results can be extracted from them. Therefore, signal processing techniques are the lynch pin that determine the value of passive recording. Most recordings will contain noise and the challenge is to detect and classify sounds in the presence of noise. Noise is a factor in all recordings because sound from animals that are far away will be affected by noise. There is no escape from this and the amount of noise on the recordings will determine how far away specific animals can be detected and identified.

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